TECHNICAL REPORT NO. 1

Shaping and Terracing of the Mediterranean

By

Erwin Raisz
Senior Researcher

Project NR 088 007

Contract Nonr-474(03)

Between Geography Branch,

Office of Naval Research

and

Virginia Geographical Institute

University of Virginia

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Project research under Contract Nonr-474(03), Charles V. Crittenden - Principal Researcher, Project NR 088 007, between Geography Branch, Office of Naval Research, Department of the Navy, and the University of Virginia.

Virginia Geographical Institute
Sidman P. Poole, Director
University of Virginia
Charlottesville, Virginia

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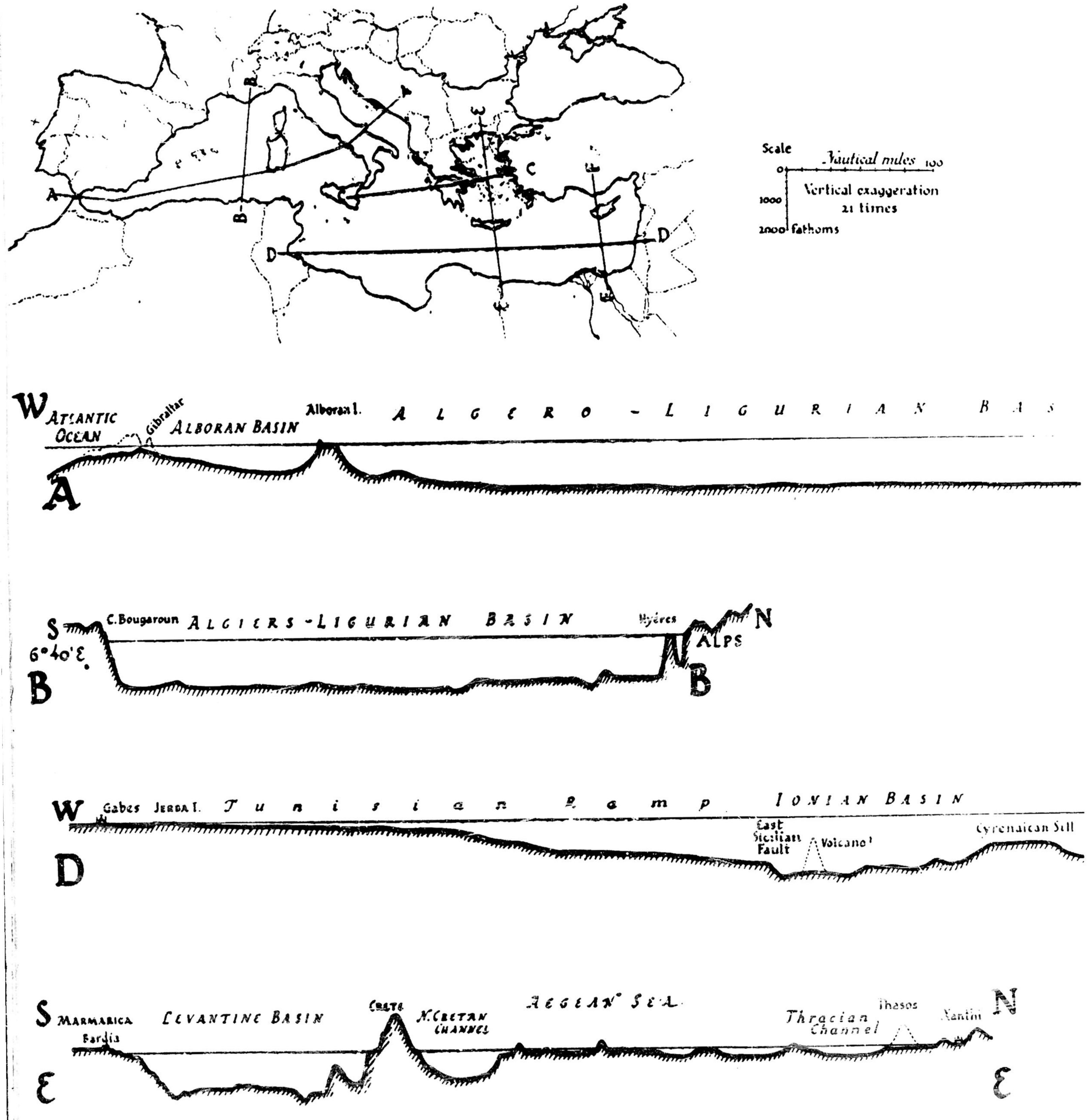
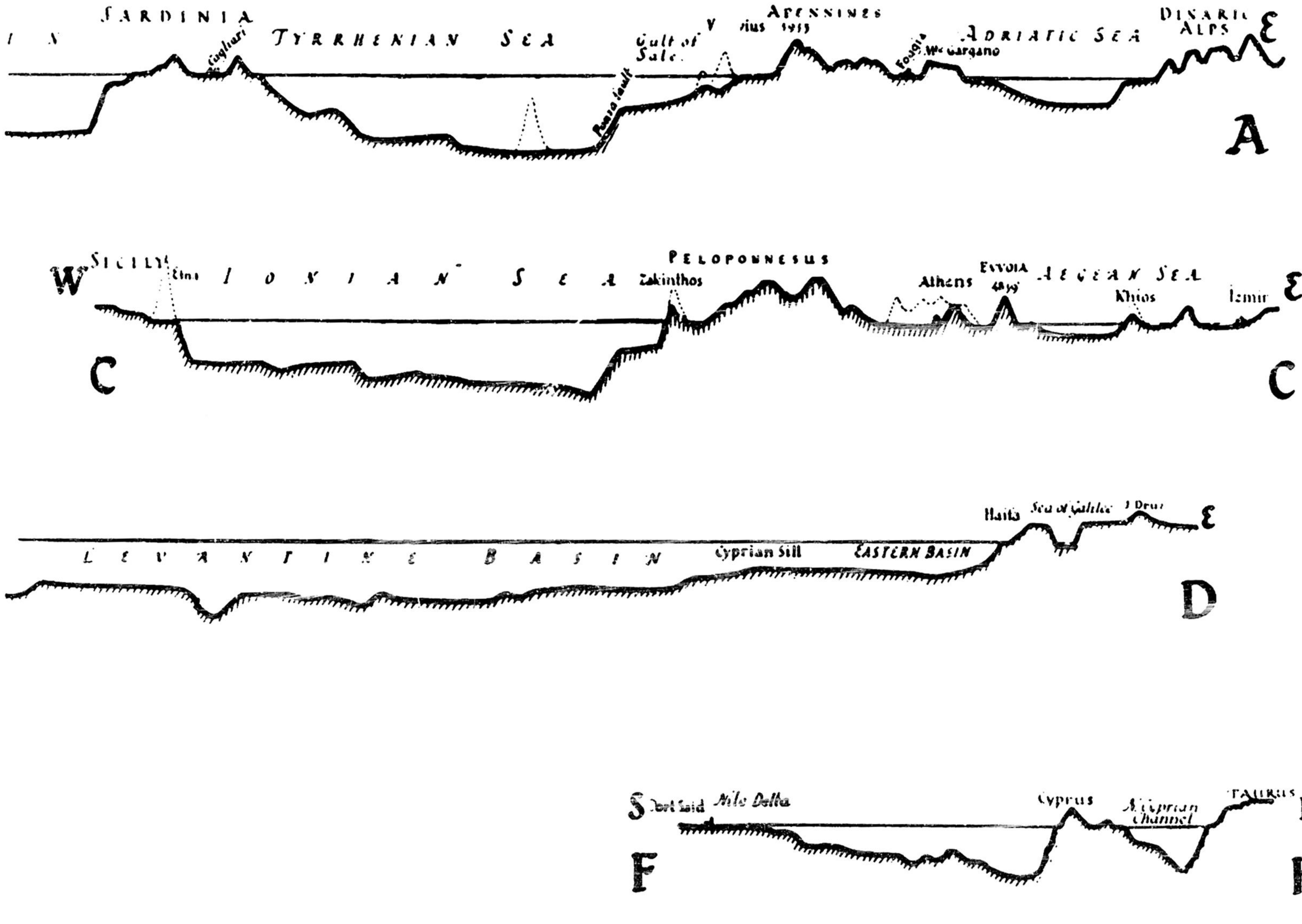


A
B
C
D
Scale
Nautical miles
0
100
1000
2000 fathoms
Vertical exaggeration
21 times
W
ATLANTIC OCEAN
Gibraltar
ALBORAN BASIN
Alboran I.
A L G E R O - L I G U R I A N B A S
A
S
6°40'E.
C. Bougaroun
A L G I E R S - L I G U R I A N B A S I N
Hyères
ALPS
N
B
W
Gabes
JERBA I.
T u n i s i a n R a m p
I O N I A N B A S I N
East Sicilian Fault
Volcano ?
Cyrenaican Sill
D
S
MARMARICA
Bardia
LEVANTINE BASIN
CRETE
N. CRETAN CHANNEL
AEGEAN SEA
Thracian Channel
Thasos
Xanthi
N
E
E

All profiles of the Mediterranean Sea - except the Tunisian Ramp - show deep basins with uniform flat floors, bordered by very steep coastal slopes. These basins are the result of downfaulting of rigid blocks but the even floors are partly due to fill with sediments. Up faulted blocks (sills) divide the sea into several smaller basins (A-A and D-D). The several sea mounts rising abruptly from the bottom are extinct volcanoes. The Adriatic Sea and the Aegean Sea are shallow interfold basins.



SHAPING AND TERRACING OF THE MEDITERRANEAN

AIM AND INTRODUCTION

This article aims to fill a gap in material available in English about the major form, shape, and terrace patterns of the Mediterranean Basin. Diverse items of European literature related to the subject would fill a library. However, no up-to-date comprehensive or summarizing work, understandable by the educated layman, has been found in the English language. Research projects under way at the Geographical Institute, University of Virginia, have brought this need sharply into focus. Something more than an empirical description of these basic physical patterns is needed in order to make worthwhile interpretations of innumerable related aspects of regional character - physical and human. Only through some grasp of the developing theories and knowledge of geology, geomorphology, and related sciences, could we gain the necessary understanding. It is felt that a similar need may exist in other centers of study and research.

Most of this paper is based on compilation, but it contains some original contribution. The writer and his research associates at the Virginia Geographical Institute* have traveled widely and made considerable field observations in the Mediterranean Region. A sizable vol-

* Gratitude is hereby expressed for support, encouragement, editorial assistance, consultation, and advice, by Sidman P. Poole, Director; Charles V. Crittenden, Chief Researcher; and Geza Teleki, Senior Researcher, of the Virginia Geographical Institute.

ume of air photography has been observed and studied. Numerous profiles have been made from recent nautical charts, and several original maps and diagrams were drawn. Personal correspondence with Mr. Pfannenstiel and oral discussion with Dr. Geza Teleki (a geologist and geographer of European training and background) helped to clear up various questions. Great aid was rendered by the Inter-Library Loan System, of the University of Virginia and especially of the Library of Congress. A numbered bibliography of principal sources appears at the end of this article; and occasional citation of these sources is made by the parenthetical numbers throughout this text.

It is probably unnecessary to suggest a bit of caution in reading this report. The processes which made the Mediterranean are extremely complex, and much that follows hereafter is necessarily a digest and simplification of what is known and theorized today. There are varying interpretations of the evidence and not all could be adequately presented. It is hoped, however, that the work will stimulate better understanding and further interest in a region which again occupies an important place in the affairs of men all over the world.

The Mediterranean Sea is unlike any other sea. Wedged between three continents, connected by narrow straits or canals to other seas and oceans, it is what its name implies - a "land-locked sea". Geologically it is most complex, and its development goes back to the earliest eras of the earth's history. From the everchanging outlines of this region during the Paleozoic and Mesozoic eras emerges a general

picture. In the south was the large, solid block of Gondwana (larger than present Africa), which was rarely submerged; in the north were located several blocks, or "shields", such as North Atlantis, Skandis, Sino-Siberia, etc. (22)

DEVELOPMENT BEFORE THE ICE AGE

THE TETHYS SEA

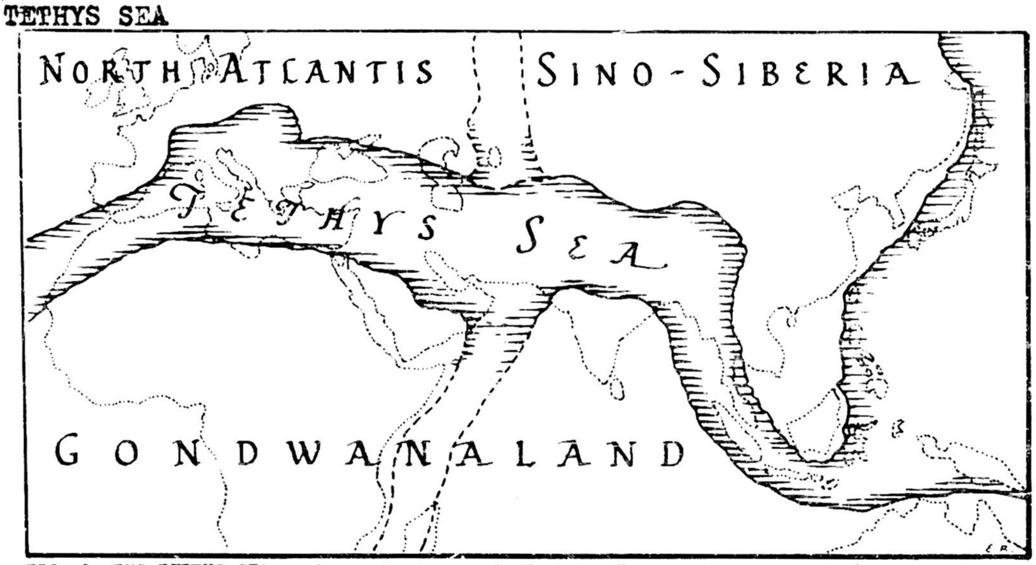


FIG. 1 THE TETHYS SEA -- An ancient sea girdled the Eastern Hemisphere before the Alpine orogeny. It varied in shape and size through the ages and often overflowed north and south. North-south extent was wider than shown here because Africa and Eurasia (dot-line boundaries) were pushed together in the Alpine orogeny.

In between Gondwana and the northern blocks was a geosyncline - a downwarped, rather mobile part of the earth's crust which was submerged and called the Tethys Sea. This sea reached to what are now India and Australia in one direction, to "Central America" in the other, and received sediments both from the north and from the south. Quite often the sea spilled over to areas which are now Germany, England, the Baltic Region, and, occasionally, into the region of the present Sahara. (21)

ALPINE OROGENY

During the greater part of the Mesozoic era, the lands north and south of the Tethys Sea were reduced by erosion and this material was deposited in the sea. Thus was the Tethys Sea filled with sediments, weighing heavily on the sub-sea crustal portions; while the land blocks were constantly worn down or degraded to become lighter.

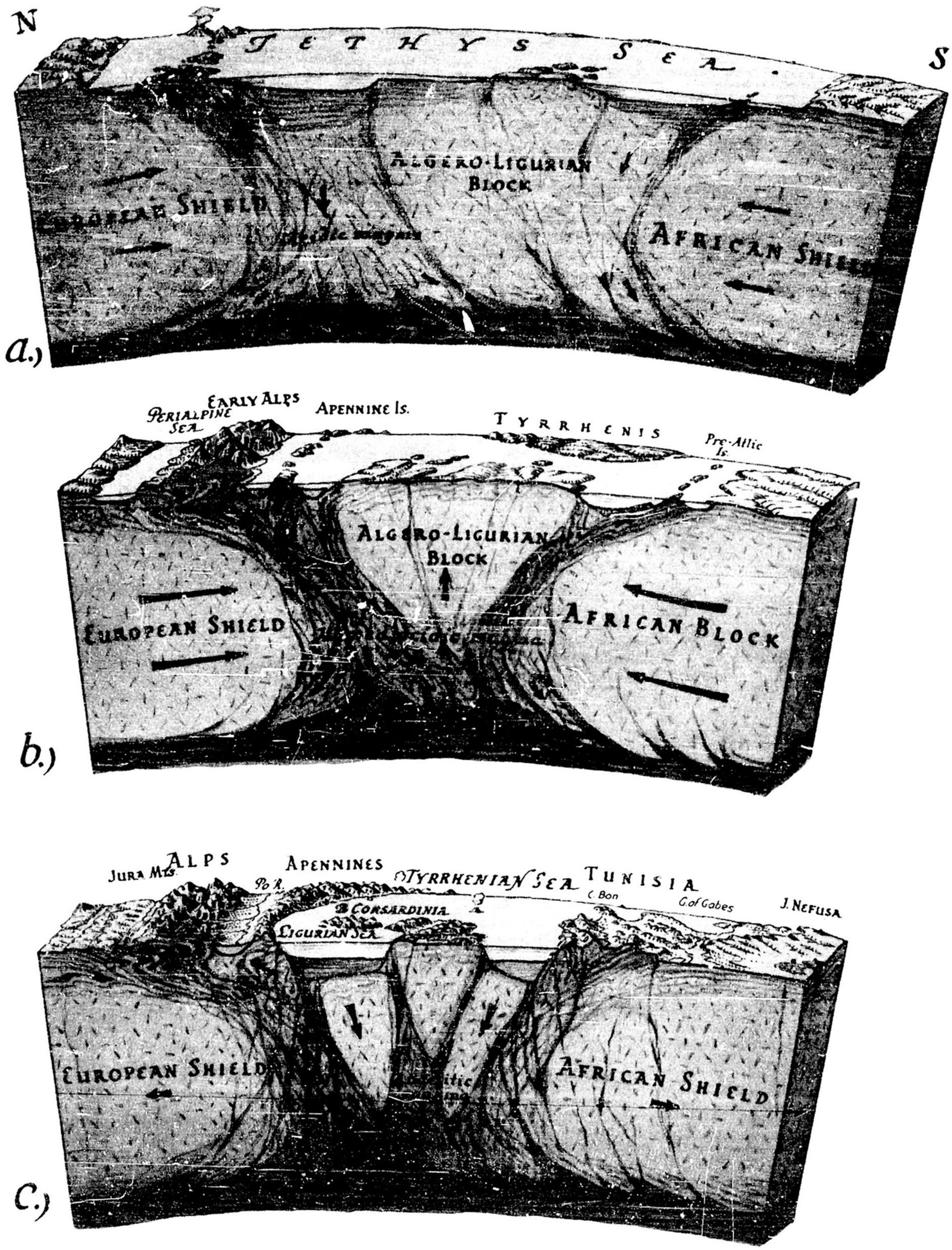
It is thought that the earth contracts and in general tends toward an isostatic balance. An equilibrium is supposed to be maintained under gravitational stress (changes in surface weight distribution) by the yielding or plastic flow of rock material beneath the surface. It is assumed that each unit column or elongated pyramidal portion of the earth, from surface to center, tends to have the same weight. The interaction of these factors produced a mountain-making period - the Alpine orogeny.

For some time during a shifting of weight, the earth's somewhat rigid crust remains inert or resists readjustment to unbalanced load. When the stresses reach the snapping point, or overcome this state of inertia, the earth undergoes an "orogeny" or mountain-making period. Such mountain-revolution (orogeny) starts at one place and then expands all along the geosynclines. The contraction moves the rigid blocks or "shields" toward each other. The sediments and the less-resistant and less-rigid masses of the geosyncline, in between the shields, are squeezed - sideways and up. The material between the shields under the greatest pressure and heat is remolded. Some of this material is squeezed under the shields where it may be completely

molten into the plastic zone. All this was accompanied with a great deal of volcanism, molten material of the granitic type ascended into the upper orogenic zone or even reached the surface along faults and fractures.

The Tethys geosyncline of early Mesozoic era is believed to have been 800 miles broad, on the average, before its later compression. Sinking kept on until the middle Cretaceous when the first phase of the Alpine orogenic cycle begins. This orogeny had many mountain-folding phases, alternating with quieter periods, to appear as a pulsation lasting up to present time. It is estimated that the net north-south contraction of the Tethys geosyncline during the period of Alpine orogeny is some 160 miles - the Mesozoic Tethys of 800 miles was compressed to 640 miles for a shortening of one fifth. (22)

The structure of the orogenic belt is far from simple. Between the great "shields" a number of detached smaller rigid bodies or "blocks" resist pressure. The compressing forces act first on the weak "channel" zones, between the blocks (see Figs. 2b and c). The interposed "blocks" seem to float in the broader orogenic belt and are shifted, tilted and broken up. Folding of masses of "channel synclines" between these "blocks" and the big "shields" provides a strongly bending, curving and recurving "band" - system of folded mountains. The major folded and overthrust nappes generally run toward the relatively lower (or submerging) shields.



N
TETHYS SEA
S
ALGERO-LIGURIAN BLOCK
AFRICAN SHIELD
a.)
EARLY ALPS
PERIALPINE SEA
APENNINE Is.
TYRRHENIS
Pre-Atlic Is.
ALGERO-LIGURIAN BLOCK
EUROPEAN SHIELD
AFRICAN BLOCK
b.)
JURA MTS.
ALPS
Po R.
APENNINES
TYRRHENIAN SEA
TUNISIA
C. Bon
G. of Gabes
J. NEFUSA
CORSARDINIA
LIGURIAN SEA
EUROPEAN SHIELD
AFRICAN SHIELD
c.)

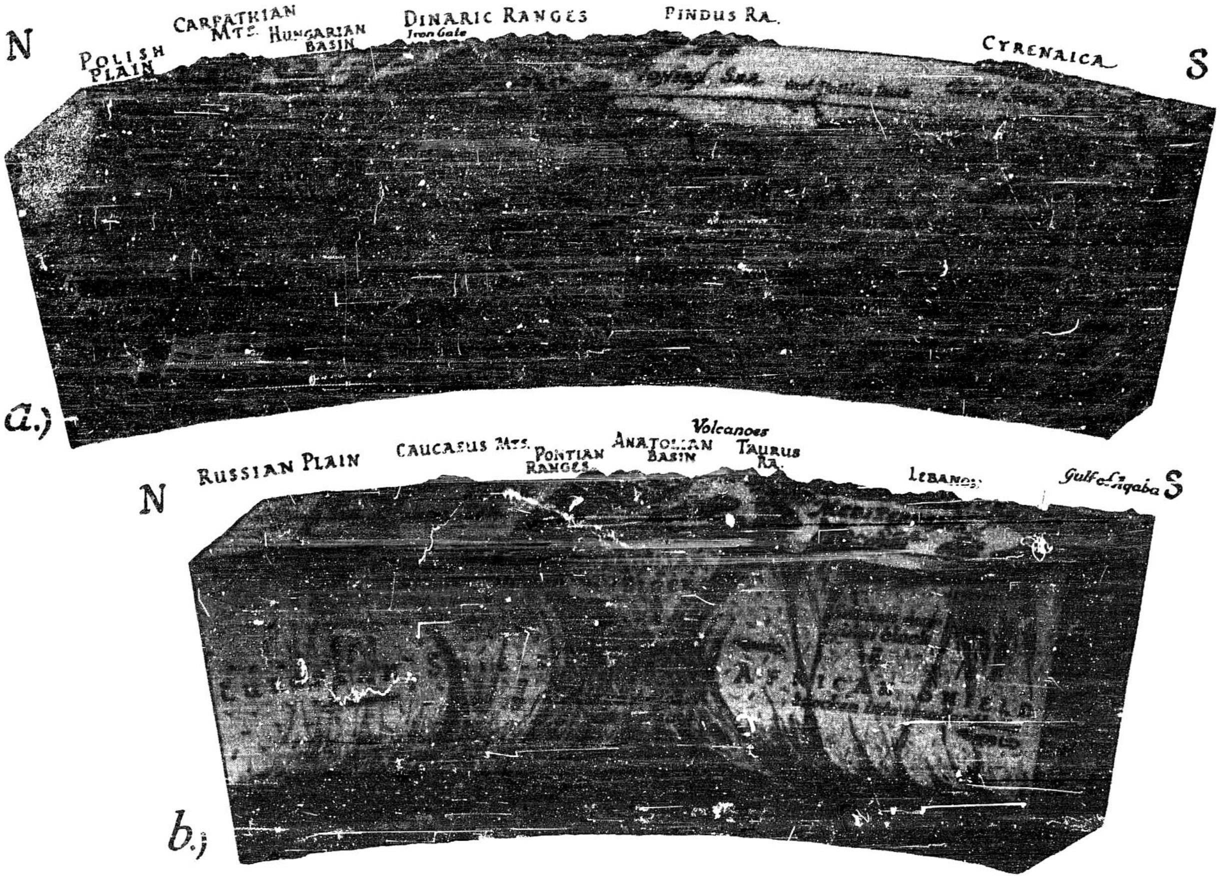


FIG. 3 EASTERN MEDITERRANEAN BASIN, SCHEMATIC NORTH-SOUTH BLOCK SECTIONS:

(a) Western portion; and (b) Eastern portion

Both sections show considerable fracturing, torsion, and up-and-down movement of blocks. Black arrows indicate direction of pressure in the earlier compressive orogeny; white arrows show movements of later dilational stages.

FIG. 2 (ON FACING PAGE) OROGENIC PHASES OF THE WESTERN MEDITERRANEAN BASIN REPRESENTED IN SCHEMATIC NORTH-SOUTH BLOCK SECTIONS:

Phase 1: (a) Compression — Earth contraction forces solid shields of Africa and Europe together — thus compressing the sediment-laden, weaker zone of the Tethys Sea.

(b) Increasing Compression — The Alps are thrust to great heights; Tyrrhenis and the Algero-Ligurian blocks emerge.

Phase 2: (c) Dilation — Forces and movement of the great shields reverse — thus parts of the central blocks sink and, around them, volcanoes belch basic lavas.

STRUCTURAL MAP OF THE MEDITERRANEAN REGION *after Kober, Stille, Seidlitz, Born and others.*

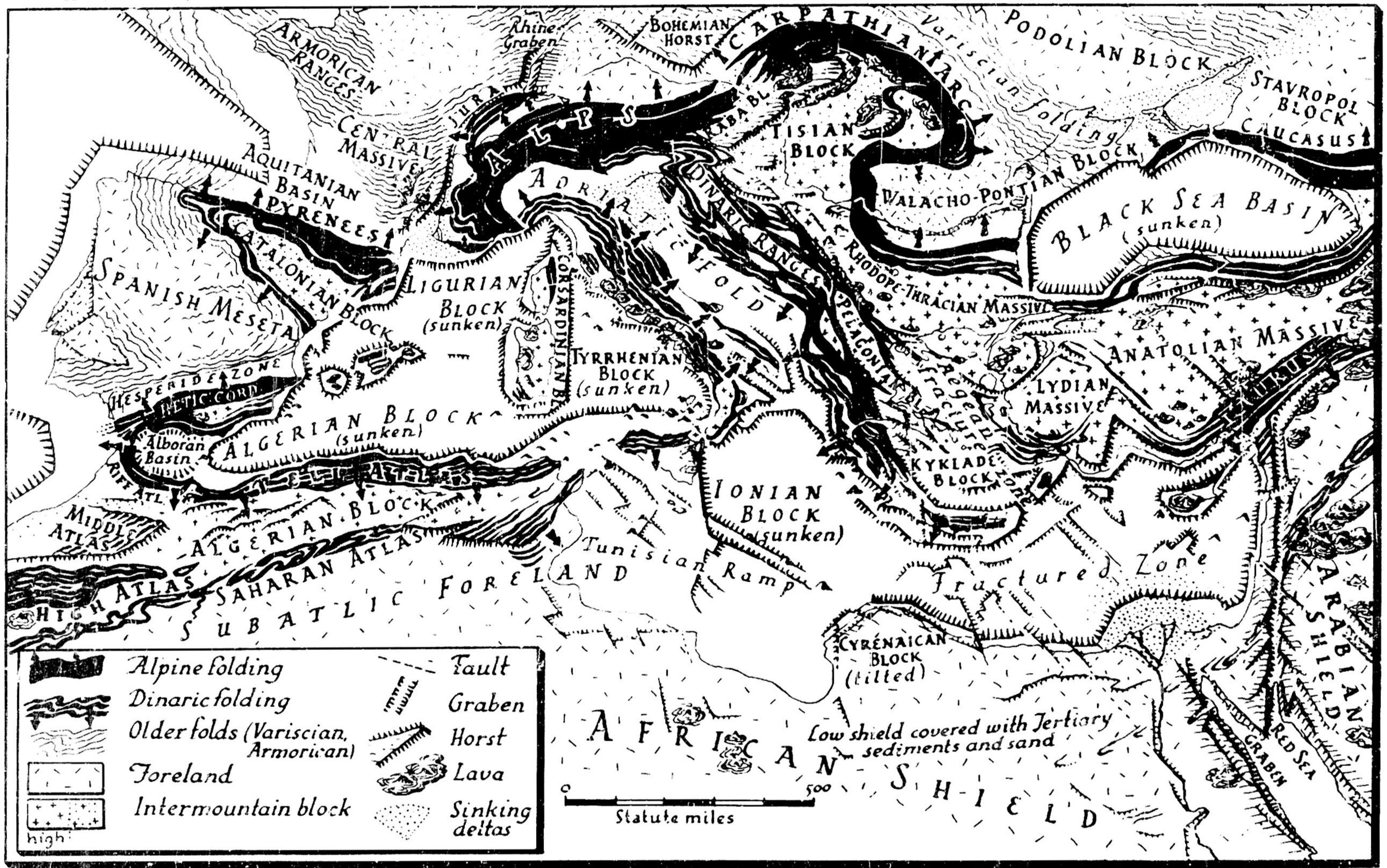


Fig 4

Volumes have been written about the nature of Alpine folding. For us it is sufficient to know that, in the Alps, Pyrenees, and Carpathians, Tethys sediments were folded and thrust toward the northern "shield"; while in the Atlas, in the western Balkans, and the Taurus Mountains, a somewhat simpler kind of folding, called the Dinaric, was directed toward the southern "shield". In between the folded ranges were the solid fragments or blocks, like the Spanish Meseta, Anatolia, and several others. Particularly important for us are the Alboran, the Algero-Ligurian, and the Tyrrhenian blocks, which occupied much of the present Western Basin of the Mediterranean Sea (47).

While the mountains were rising, they were attacked by rain and rivers. Great thicknesses of sediments were deposited near the shore - gravel, sand, marl, and clay. We find these solidified and folded, fossil-poor beds, called Flysch, from France to Indo-China. In the Mediterranean region, Flysch is found in the western Apennines (Flysch-Apennines), lifted later to heights reaching 1700 meters. In Crete a much-disturbed Flysch is found at even greater heights. (44) Sedimentary formations of gravel, sand, occasional coal and selt, which derived from fans and talus of the higher mountains of a later stage, are called the "molasse" and are common along the Spanish and French coasts. Gibraltar was not yet in existence, but seaways south and north of it allowed a warm-water Atlantic fauna to invade the forerunner of the Mediterranean Sea. (47)

Alpine orogeny was not all compression. The movement of "shields" accelerates first toward compensating the unbalanced situation; and


The Mediterranean Region in the Middle MIOCENE period
500 Km.
500 miles
URAL Mts
RUSSIAN TABLE-LAND
SARMATIAN SEA (brackish)
CAUCASUS
CRIMEA
PONTIC SEA
PONTIC RANGES
ANATOLIAN BLOCK
ARABIAN BLOCK
Possible land block
MEDITERRANEAN SEA
SAHARAN CONTINENT
NORTH SEA
NORTH ATLANTIS
Shallow Sea
Peat-bogs
ATLANTIC OCEAN
Armorican
RHINE MASSIV
BOHEMIAN MASSIVE
CARPATHIANS
PANNONIAN SEA
BIHAR
DACIC SEA
RHODOPE MASSIVE
MASSIF CENTRAL
Cisalpine Sea
ADRIATIC SEA
DINARIC
IONIAN BLOCK
TYRRHENIS
ALGERO-LIGURIAN BLOCK
CATALONIAN SEA
PYRENEES
SPANISH MESETA
Sub-Betic Chan.
ALBORAN BLOCK
Sub-Riffian St.
ATLANTIC ARCHIPELAGO
Reiss

Fig 5


THE MEDITERRANEAN REGION
in the PLIOCENE period
after L. Wills, Furon, Kossmat and others
500 miles
500 Km.
ATLANTIC OCEAN
NORTH SEA
RUSSIAN PLAIN
URAL MTS.
Volga
Don
Elbe
Peat deposits
ARAL-CASPIAN SEA
(brackish)
SARMATIAN SEA
CAUCASUS MTS.
BLACK SEA
(brackish)
Dacic L.
Pannonic L.
CARPATHIAN RA.
Danube
Rhine
Rhone Gulf
PYRENEES
BETIC CORD.
Str. of Gibraltar
WEST BASIN
ADRIATIC SEA
ATLAS MTS.
EAST BASIN
Persian Gulf
Volcanoes
Nile

Fig 6

then, because of inertia, it surpasses the condition of balance and swings like a pendulum over the "dead point". The movement now reverses. During the backswing period, dilating occurs, broadening the synclines. The rigid blocks tilt and break and slide down along the tectonic fractures, thus presenting a secondary period of sinking and marine ingression. The pendulum swings again and orogeny of a next phase comes into being, followed by another sinking or dilating period - and so on. This pulsation is part of every orogenic cycle of the globe. (21, 23) The Alpine orogeny began with a weak phase in the Middle Cretaceous, after which the forcefulness of the orogenic phases increased and reached their peak in the Eocene. Then there was a decrease of intensity up to the present, with two phases of secondary intensity-peaks in the Miocene and in the Pliocene. The dilating periods, however, had the opposite pattern. The greatest broadening occurred in the Middle Mesozoic, became less and less toward the Eocene, and increased since. (Stille)

Both processes were responsible for shaping the Mediterranean region. The majestic mountains were the result of the contracting phases mostly in the earlier stages; but the basins and rift valleys sunk to their various depths in the later periods.

MEDITERRANEAN SEA

During the dilating stages of Alpine orogeny, block faulting was prevailing. The most important event was the foundering of the Alboran, the Algero-Ligurian, and the Tyrrhenian blocks and the creation

of the Western Basin of the Mediterranean Sea. It was not a smooth process; many volcanoes flared up, particularly around the Tyrrhenian Basin, and the Etna-Lipari-Vesuvius chain of volcanoes originated at this time. While granitic (acid) type of lavas prevailed in the mountain-molding phases, andesites and basalts (the basic type of lavas) poured forth from greater depths in the dilating periods. (22)

The foundering was complicated by some torsional forces. In general the Western Basin was forced more to the northward than the Eastern Basin. (44) The specific mechanics of this are not well understood. The foundering of the western blocks was compensated with a rise around them in the Atlas Mountains, in the Betic Cordillera in southern Spain, and in the Apennines. The Strait of Gibraltar was opened while the adjacent seaways closed. (47) Through such varied processes, a flat-bottomed basin about 3,000 meters deep was formed, with steep sidewalls and occasional volcanic peaks, and some submarine scarps.

Fig. 6 shows the closing stages of Alpine orogeny in the Pliocene period. The picture is not very different from the present outlines. The Sarmatian Sea was beginning to break up into lakes and smaller seas. (47) A wide landbridge then connected Europe and Asia over which elephants, rhinos, horses, etc., migrated - to be hunted by early men. One fact shows up clearly on this map - even better than on a map of the present - that the Mediterranean Sea is really two seas, accidentally connected. The Western Mediterranean Sea became a downfolded basin completely surrounded by Alpine-folded ranges. Similarly, the

Bottom Configuration

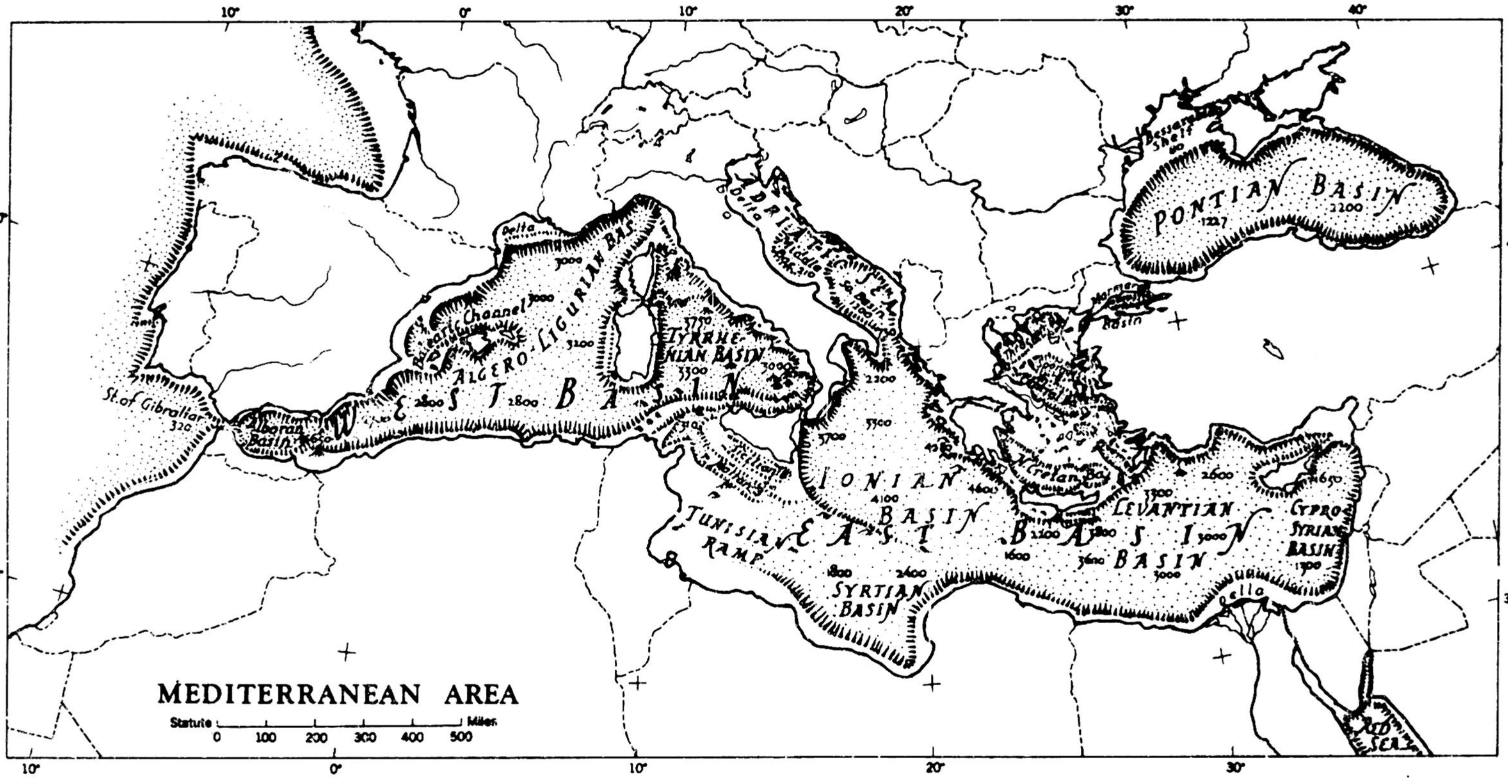
- Land and continental shelf
- Continental slope.
- Basins

Depths in meters

Sea mounts

FIG.7 The Mediterranean Sea consists of two large basins, of somewhat different origin and accidentally connected. Both the East Basin and the West Basin are divided by submarine rises into smaller basins. All basins have flat bottoms and very steep continental slopes - with one exception. The Tunisian rump is a submerged "subalpine foreland" (see text). Several sea mounts, probably volcanoes, rise abruptly from the bottom. Submarine canyons, too small to show on this map, cut deeply into the continental slopes.

The bottom of the Mediterranean Sea is covered by foraminifera ooze. The thickness of sediments ranges from 100 to 2700 meters (Weibull, 1947).



Adriatic Sea and the Aegean Sea are much shallower between-fold basins. The Eastern Basin, however, originated as a "sub-alpine foreland". All along Europe and Asia, the Great Tertiary Mountains are flanked on the south by a lowland, which is at many places submerged. We find such a lowland south of the Atlas Mountains, and in the area of the present Chotts of Tunisia-Algeria. Low parts and basins of Mesopotamia, the Persian Gulf, the Arabian Sea, and the Indo-Gangetic lowland, etc., are also such foreland type of depressions. If the lowland south of the Atlas Mountains were today a few hundred meters lower, the Eastern Basin would thereby connect with the Atlantic, as it was indeed connected in the earlier periods. The only major shallow portion of the Mediterranean Sea is the Tunisian "Ramp" where the bottom of the Eastern Basin gradually rises to the Chotts, as shown in Fig. 7.

This, however, is not the complete picture. Similarly to the Western Basin, the Eastern Basin also foundered and was broken up by block faulting. The former subalpine foreland sank along faults to about 3,000 meters, a similar depth to that of the Western Basin. Thus we have here somewhat of a "graben" structure - an east-west elongated, down-dropped block of the earth's crust. East of Sicily and Malta is a 1,000 meter wall of a submarine fault scarp, along which the Ionian Sea foundered to its great depth. Besides these major displacements, the whole Mediterranean area is criss-crossed by fault scarps. Particularly important are a series of northwest-southeast faults which did much to shape Greece and the Aegean archipelago. (44) Besides the east-west elongation of the basins, there is also a series

of north-south anticlines and synclines which break up the Mediterranean Sea into smaller basins, named on Fig. 7.

The eastern end of the Mediterranean Sea looks as if the great east-west down-dropped foreland had been abruptly cut off. This is exactly what happened as the result of the northward extension of the Great Rift Valley of Africa. It is beyond the scope of this paper to discuss the origin of rift valleys. Their nature is shown, by Fig. 8, as an elongated "graben" with elevated ramps on both sides and much volcanism all along.

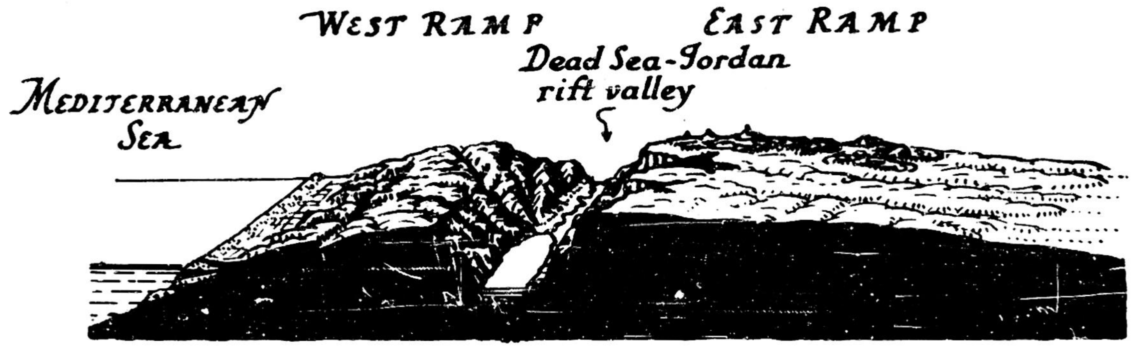


FIG. 8 THE JORDAN-BEKAA RIFT VALLEY AND ITS TWO SIDE-RAMPS

In this case the graben is the Aqaba-Jordan-Bekaa "valley", bordered by the Judea-Lebanon Mountains on the west and the Syrian plateau in the east, Hundreds of craters south of Damascus and near Homs testify that volcanism was not wanting. This rift valley was formed in the later dilating stages of the Tertiary period.

This chapter has outlined the development of the Mediterranean region through the Mesozoic and Tertiary eras. The ancient Tethys Sea was broken up by Alpine orogeny. The contracting and dilating pulsa-

tions of this revolutionary period were briefly analyzed. Likewise outlined were the processes whereby the great ranges were forced upward, followed by sinking and rifting, until the major shape of the Mediterranean Sea was clearly recognizable at the beginning of the Quaternary era.

Thus at the end of the Tertiary era the major structural elements of the present Mediterranean region were all there, but this is not the end, however, of the ups and downs of the region. Although structural changes still go on - as we are so vividly reminded by the Ionian earthquake (1953) - the major changes in the Quaternary era were controlled largely by glaciation as described in the following.

ICE AGE PATTERNS - MARINE TERRACES AND DEPOSITS

Under Ice Age we understand the period of great glaciations of the Quaternary era including the interglacial stages. It is now well established that great ice sheets covered much of North America, North Europe, the Alps, etc., in the geological yesterday. There is far less agreement upon causes of the glaciations. Some advance the ideas of lessened sun-radiation, others of more volcanic dust and carbon dioxide in the atmosphere. Some scientists connect it with astronomical causes. There is even a theory that warmer climate, but greater snowfall was the cause. That it may have had something to do with Alpine orogeny is supported by the fact that, after other great orogenies in the geologic past, there were other glaciations. The merits of the various

TIMECHART OF THE ICE AGE IN THE MEDITERRANEAN REGION

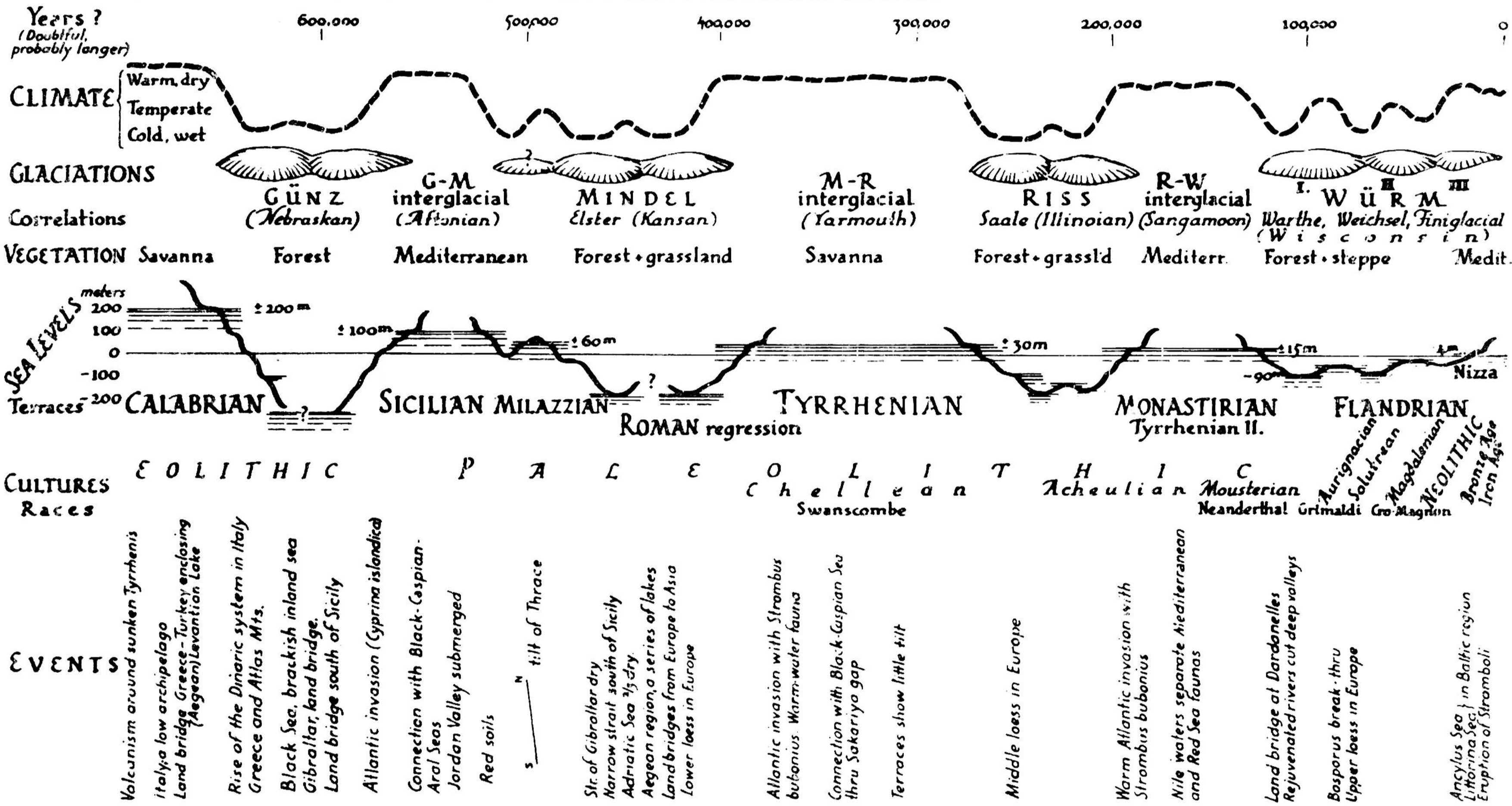


Fig. 9 This timechart is based on the works of Pannenstiel, Blanc, Gignoux, Denizot, Wright, Woldstedt, Zeuner, and others.

There is, however, no glacial chronology universally acceptable to all authorities.

hypotheses can not be discussed here. The fact remains that at least four times did the ice advance over Northern Europe. In the first, it advanced from the Scandinavian center as far south as the line of present London, Amsterdam, Cracow, and Kiev; the later advances went less far southward. Corresponding glaciations are recognized in the Alps. The interglacial stages were probably longer than the glacial stages, and in most of them the climate was warmer than at present. Now we are living at the end of one of the glacial stages; the ice caps of Antarctica and Greenland are still here.

Each glaciation withdrew millions of cubic miles of water from the oceans, piled it up in the form of ice and lowered the sea level by hundreds of feet. In each interglacial stage the ice melted, causing a marine transgression. At its higher levels the sea cut terraces and deposited fossil-bearing sand and gravel upon them. These terraces now remain somewhat brokenly encircling the Mediterranean; their study contributes greatly to an unraveling of the history of these times.

1. THE CALABRIAN TERRACES

At the end of the Tertiary, the sea probably stood 150-200 meters higher in average relation to the land than at present. Marine terraces had notched the land margins, and characteristic forms of life became fossils in sediments upon those coastal shelves. Three-quarters of these fossilized species are now extinct. Some of these terraces now stand in Calabria at various levels such as 300-400 meters, 550-700 meters, 1000-1300 meters above sea level (lower in the north, higher

in the south) - thus indicating that Italy was a low archipelago which was rising at that time. (16) On the other hand a landbridge connected Europe and Asia, and the Aegean depression contained only a series of lakes. (47) The Syrtiac Bay (present Gulf of Sidra) extended well into Saharan Africa, while Cyrenaica stood out as an island. Marine fossils correlated with the Calabrian are also found at more normal elevations in the Po Valley, Cyprus, and Sicily.

2. THE POST-CALABRIAN STAGE AND THE FIRST GLACIATION

At this time the climate became colder, indicated by the cold-water fossils of some of the lower Calabrian terraces. (18) In the Alps the abundant snows could not melt off completely during summers; in time a heavy ice cap formed, above which ice plateau only the highest peaks protruded. Much larger ice masses were formed in North Europe, North America, and Antarctica. More and more water was withdrawn from the sea and piled up in the ice caps. Such ice caps depressed parts of the earth's crust and made place for still more ice. At the height of glaciation, it is thought that enough water was withdrawn from the oceans to decrease depths by hundreds of meters. Shallow seas ran dry, land bridges formed; and thus developed the first regression. The Straits of Gibraltar and Bosporus were dry; and the Mediterranean became one, or perhaps two, cold inland seas. As it is very difficult to trace shores which are now under the sea, the extent of this regression is not known - perhaps 200 meters below the present level or about 400 meters below the Calabrian level. (35) The Strait of

Gibraltar is today 320 meters deep, but probably reached this great depth by later down-faulting. (36)

There are some indications that this lowering of sea level may have been much greater than generally thought. In this case animals could have migrated freely from Africa to Sicily and Europe. The fauna of both continents then appeared the same. The early man of Abbevillian and later Chellean cultures left chipped tools in their caves and camps.

This was a time of crustal unrest. Block faulting in the eastern Mediterranean elevated Greece, broke down the Aegean and Marmara troughs, and Italy was bodily elevated; while in the United States the Cascadian Revolution shaped the Pacific coastal region.

Most geologists correlate this with the Guns glaciation in the Alps or the Nebraskan in the United States. The Guns glaciation is variously estimated as 600,000-1,000,000 years ago.

3. SICILIAN STAGE

The climate turned warmer, and in time the great ice caps dwindled. Meltwaters filled the Mediterranean basins again, but not quite up to the Calabrian level. Cold Atlantic waters swept through Gibraltar, and Suez was under the sea. The deeply-depressed North Europe was gradually rising. A slight tilt in the terraces in France and Italy is probably due to upwarp in the periglacial areas toward the former ice centers. *Ostrea edulis* (oyster) shells were deposited in sands, today in terraces at 80 meters in Sicily and near Pisa. (5)

(9) (16) Terraces at 95 meters in Lebanon, 94 meters in Algeria, 75 meters in Catalonia, and 95 meters on the Riviera are probably the same age. (28) The Mediterranean was connected with the large Black-Caspian-Aral Seas, not through the Bosporus, but through the Sakaria river-gap farther east. (34) Yellow clays, with snails indicating a dry, warm climate, were deposited in Southern France, red soils in Corsica.

Volcanism was intense and commonly associated with tectonic instability all through the early Ice Ages. This is indicated by fresh lavas in Libya, Syria, and Tripoli. (37, 38) Volcanoes are known to have reddened the sky in Southern France, and in Italy volcanic tuffs cover some of the terraces. The terraces in Cyrenaica and the Atlas region were slightly tilted upward to the west; and Thrace was somewhat uptilted northward - thus indicating some post-Sicilian crustal movement. (34) The terraces at 95, 65, and 45 meters in Lebanon, however, do not show tilt along their north-south extent. (49)

The climate of the period ranged from cold to what we now call Mediterranean type. This was comfortable enough for the early people who left us crude campsites and tools of Chellean type. (30) They hunted animals extinct today, such as the Elephas meridionalis, Equus antiquus, Cervus elaphus, etc. (36) The Heidelberg man may be of this age. Only one half of the marine species of the Sicilian exist today.

The Sicilian stage is variously dated 500,000 to 660,000 years past, and several other aspects remain as partly-solved problems. At Milazzo in northern Sicily a terrace is described at 60 meters; similar

terraces are found in Lebanon, Sardinia, and other regions. These are poorly developed and carry a nondescript fauna of neither Sicilian nor Tyrrhenian species. (9) Pfannenstiel regards these as evidence of a later stage of the Sicilian (36); others, like Zeuner (50), however, assign them to a later age correlating with the Mindel-Riss interglacial times (Penultimate Interglacial). In America, the Sicilian is correlated with the Aftonian interglacial stage.

4. THE ROMAN REGRESSION

Once again the climate turned cold. A new ice cap formed over the northland (Elster glaciation) and huge glaciers, the Mindel glaciation, descended from the Alps and Pyrenees. In North America the icy fingers of the Kansan glaciation shaped the course of the Missouri River. Whether this glacial stage took more water from the sea than the Gunz is not well known for the same reasons mentioned before. The shoreline patterns of the Roman Age are at present well below the present sea level - perhaps 200 meters or more. The only evidences are found in sand and gravel extending, at that depth, out beyond and below present river mouths, and in some other submarine forms, which could have been deltas or benches, submarine valleys, etc. But, whether these date from the Roman stage or from some later regression is hard to prove. Not enough deep borings on the coasts and shelves have been drilled or studied to give a firm chronology. However, the Mindel was an extensive glaciation, and it seems reasonable to assume a general 200-meter lowering of the sea from the present level. This would mean a

300-meter lowering below the Sicilian terraces.

Most of the Aegean and Adriatic Seas were dry. (5) A bore hole on the northernmost Nile delta encountered fresh water in the sand strata at 167 meters without reaching sub-delta bedrock. (36) This fresh water may well have been preserved in sand, deposited at the lowered sea level.

FIG. 11 ROMAN REGRESSION IN ITALY (after Blanc) The sea level was probably 200 meters lower than at present.

Gibraltar was probably dry, at least part of the time, and the Mediterranean was almost split into two basins, but faunal evidence shows that for most of the time the Sicilian Strait was open. Malta, Crete, and perhaps Cyprus were attached to the continent of Europe. Rising sea level and down-faulting later made them islands; and this isolated the elephants and some other animals, which, thereafter, degenerated into

dwarf forms. (5) Although the sea of the Roman Regression was cut off from the oceans, its level was relatively steady. Lower evaporation, higher rainfall, and larger inflow from rivers compensated for the loss of intake from the Black Sea.

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DIFFERING CORRELATIONS DURING LATER ICE AGES -- What appears to have been a considerable period of time between the Roman Regression and the last glaciation left various marks and clues, which are generally fragmental or only partially understood and correlated. There is a poorly developed terrace around the Mediterranean at about 60 meters, the Milazzian, a very prominent terrace at 28 to 35 meters called the Tyrrhenian, and a universal fresh-looking terrace called Monastirian at 12 to 15 meters. The correlation of these terraces is still debated. Blanc and Pfannenstiel regard the Milazzian as being a later development of the Sicilian stage, the Tyrrhenian terrace as of both the Mindel-Riss and the Riss-Würm interglacial times, and the Monastirian as representing a later stage of Tyrrhenian II. (5) (35) Zeuner regards the Milazzian as one of the great interglacial stages (Penultimate Interglacial). (50) Others regard the Tyrrhenian altogether as of the Riss-Würm stage. Certainly a great deal more investigation is necessary before a generally accepted correlation can be made. For the purposes of this discussion, the Milazzian is tentatively regarded as a later stage of the Sicilian, the Tyrrhenian as Mindel-Riss, and the Monastirian as of Riss-Würm age.

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5. TYRRHENIAN TRANSGRESSION

The Tyrrhenian Transgression seems to have left well-marked coastal terraces. All around the Mediterranean a very conspicuous terrace runs at about 28 to 35 meters (around 100 feet). This terrace is characterized by Strombus bubonius, a warm water sea shell, which is now found on the tropical shores of the Atlantic in Morocco and Senegal. (36) This terrace shows little tilting or variation in height - Sardinia, 35 meters; Italy, 35 meters; and Fayum, 34 meters. (9) (19) In Lebanon a 45-meter terrace is conspicuous and probab' of Tyrrhenian age - the elevation of which may be due to a later rise of the land. (49) In Corsica this 35-meter level is the highest terrace, thus indicating that this island may have sunk considerably before the Tyrrhenian stage. Even post-Tyrrhenian instability is indicated by the fact that, locally, fossil-bearing Tyrrhenian terraces are found to extend under more recent fluviatile, or marine, Flandrian deposits (Etang d'Urbino). (25)

Distinctive connections appear to mark this stage in Medi' ;anean evolution. Atlantic waters and life forms again entered through the Strait of Gibraltar. The connection with the Black Sea was through the Sakaria river-gap - the Bosporus was not yet open. That waters connected with the Mediterranean invaded the Black and Caspian Seas is indicated by some shells of edible oysters (Cardinus edule). A 30-meter uplift is recorded in the Marmara Sea region, possibly because of the "rebound" of land which was depressed by the weight of the ice during the previous glaciation in Northern Europe. (34) A connection

with Aral-Caspian Sea was likely during the earlier stages, before the slow rebound was completed.

During the long warm Tyrrhenian stage, red soils developed in France, Sardinia, and Africa. An older loess, bearing concretions and found in many places in the Balkans, may be of this age.

By somewhat elastic estimates the Tyrrhenian took a very long time - from 400,000 to 250,000 years - and is called the Great Interglacial. It is thought to correlate with the 30-meter Wicomico terrace of the Sangamoon interglacial in Florida. If true, it indicates an eustatic stage of global proportions. (7)

There is just as much controversy in correlation of cultures as there is with terraces. Some authors assign Chellean, others Levalloisian, but most assign the Acheuilian culture to the Tyrrhenian stage. There is no question, however, as to the presence of abundant human life during this stage. (30)

6. RISSIAN REGRESSION

If the Tyrrhenian terraces were cut during the Mindel-Riss interglacial stage, it is necessary to postulate a regression of the sea when the Riss glaciation withdrew great amounts of water from the oceans. This piled up as ice in the Alps and upon Northern Europe where it is called the Saale glaciation and corresponds to the Illinoian ice stage in North America. The littoral borings examined by A. C. Blanc indicate such regression. (3) Otherwise we know little about this stage. The indications are perhaps 150 meters below sea

level, but are hopelessly mixed up with marks of the earlier Roman and the later Würm regressions.

In the cold periglacial barrens, especially winter winds carried much dust and deposited it in the surrounding grasslands in the form of loess. Several layers of loess cover parts of France, Germany, Hungary, and the Balkans, and their correlations to glaciations have been attempted.

7. MONASTIRIAN (TYRRHENIAN II) STAGE

The freshest looking terrace around the Mediterranean Sea stands some 12 to 15 meters above the present shores. Although the wave-cut coastal bench is generally less wide than in the case of the 30-meter terrace, the coastal cliffs are sharply cut and commonly undercut by waves, forming sea caves. In the sands on the bottoms of these caves are the shells of the aforementioned *Strombus bubonius* (Lamarck), and *Conus testudinarius* (Martini), *Natica lactea* (Guilding), etc. These species are missing at present - thus indicating a warmer water than now found in the Mediterranean. Examples of these cliffs and caves are well known in Gibraltar, in Spain, on the Balearic Islands, and in Corsica; but the name of this stage came from Monastir in eastern Tunisia. (36) The famous Grimaldi caves near Monaco (6), the caves of Palermo, and the long row of hollows in the cliffs of the Syrian coast are readily visible to the seafarer. We also find these caves on the Prince's Islands near Istanbul in the Marmara Sea and all along the Black Sea - as near Varna and in the Crimea. They all contain a

Strombus bubenius fauna. (36)

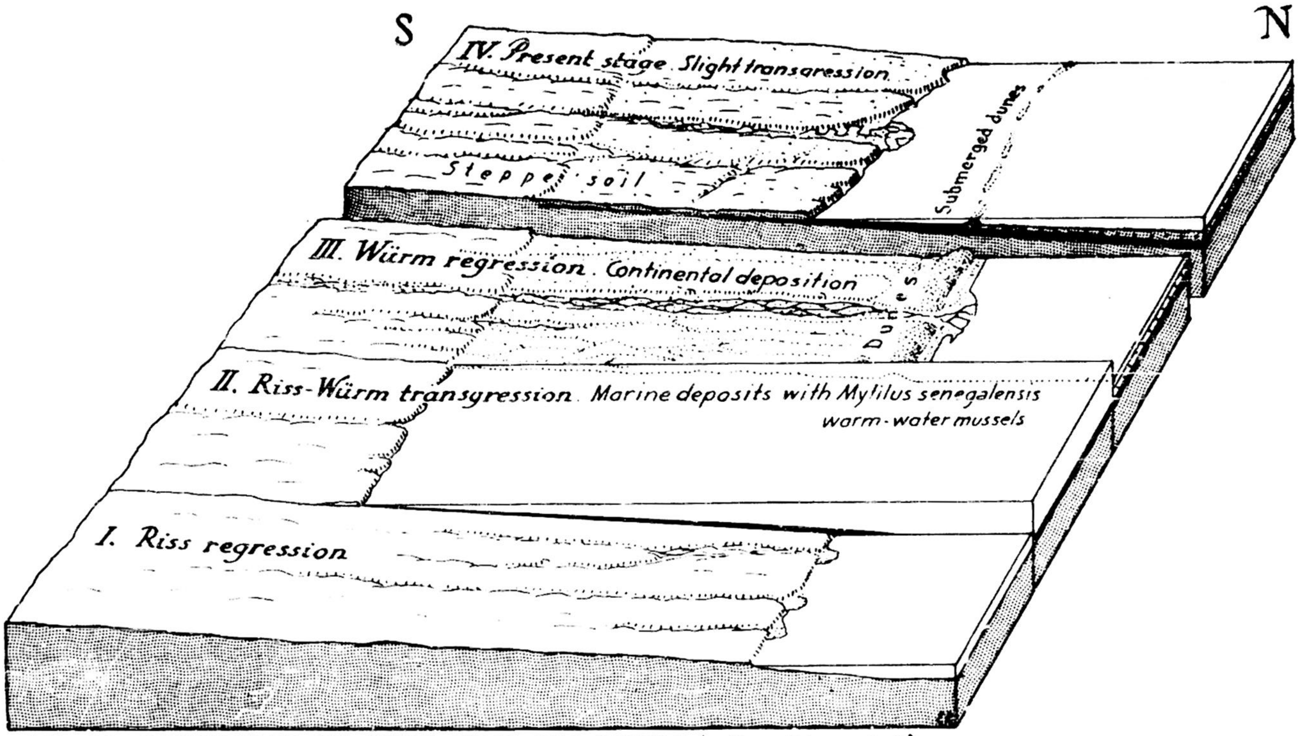

FIG. 12 EVOLUTION OF THE JEFARA COAST NEAR TRIPOLI (after Lipparini)
Both continental and marine deposits are at higher levels farther inland.

The Strait of Suez was flooded. Yet the fauna of the Indian Ocean and Red Sea did not mingle with that of Mediterranean-South Atlantic character. The answer to this puzzle lies in the Nile. At that time this mighty river ran in an easterly course from the vicinity of Cairo, cut terraces somewhat above 15 meters, and spread its sands upon the area of the present Suez Canal. There the stream sands became interbedded with marine deposits - a condition indicated by the respective presence of fresh-water shells in the riverine sands, Strombus-bearing Mediterranean layers extending from the north, and identifiable Red Sea beds reaching here from a southerly direction.

(Fuchs) So strong was the influx of fresh water that it appears to have prevented the mixing of the marine faunas of the two seas. The present Nile delta was missing until a later spread to the northward. (36)

The Bosporus was still not in existence, but Mediterranean waters linked with those of the Black and Caspian Seas. The abundant melt-waters from the Black Sea reached the Marmara through the Sakaria river-gap, passing from Adapazar to the Gulf of Ismit. Another connection east of the Bosporus through the Ergeni-Maritza lowland is recognized by Loczy and Teleki. The Black Sea waters were connected through the route of the present Manych Canal with the Caspian. Mediterranean mussels, such as Cardium edule, invaded even the less salty waters of the Caspian Sea, where they still survive. (36)

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THE LAST GLACIATION -- After the Monastirian (Tyrrhenian II) warm period, the climate became cold again and the ice piled up. We are today living at the closing stages of this glaciation. It is called the Würm in Europe; in America it bears names of the Iowan and Wisconsin, with the Peorian interglacial substage between. In Europe there were three major re-advances, called the Würm I, II, and III, with warm periods in between during which the ice front retreated far to the north.

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8. THE WÜRM I (Post-Tyrrhenian Regression)

About 150,000 years ago - the fourth time since the Günz glacia-

tion - the climate became gradually colder. As ice accumulated in the north, the sea level was lowered and the former sea caves became dry. The Strombus-bearing sands at the bottom of the caves were covered first by layers of clay derived from the weathering of the cave walls. In these clays we find the charcoals, kitchen refuse, and the chipped flints of man of Mousterian culture, along with bones of the elephant, rhinoceros, hippopotamus, hyena, etc., showing that the climate was not yet cold. Then it became colder. Frost cracked the cave walls and sharp stones fell upon the clay, forming a layer in which we find the bones of reindeer, marmot, and mammoth. Apparently the shivering human inhabitants moved to more genial southern lands. (36)

As more and more water was withdrawn into ice, the sea depths decreased. The total was about 105 meters; but this is a level 90 meters below our present sea level - considering that the Monastirian sea was 15 meters higher. This lowered level was proven by Blanc by borings in the Pontine marshes and in Versilia, north of Pisa, where peat and moor soil and lake beds were encountered down to 90 meter depth as shown by Fig. 14. (3) Similarly Pfannenstiel examined the numerous borings in the Jaffa plains and found rough river-laid gravel down to a depth of 90 meters. This gravel can now be traced higher and higher landwards until it connects with the river terraces of the present - thus forming a key horizon for the archeologist. This older gravel, with lenses of river and lake beds bearing land snails at depths down to about 45 meters, belongs to this regression. Farther inland, dunes were built which later weathered to the red sands - now the favorite soil of the

Jaffa oranges. Similar conditions are now found at the Nile delta; its front lobes rest on a rough sand and gravel bottom at a depth of 90 meters. (36)

In shoreline extent the Mediterranean Sea shrunk but little. So steep were most of the nearshore slopes that even a 90-meter regression did not change the map very much - as shown in Fig. 13.

The greatest changes were around Italy. Dry land of Sicily was extended towards Africa so that only a 10-mile strait separated the Western and Eastern Basins of the Mediterranean Sea. Sardinia and Corsica made a single large island. (4) The northern third of the Adriatic Sea was then a swampy lowland. Sands and gravels were deposited on this lowland by the extended lower course of the Po River and its tributaries of those times. The channels of these rivers can still be detected under the sea; a map of their courses was published by L. de Marchi. (8) Such an amount of sand and gravel was deposited by these rivers that the northern Adriatic would probably be dry even now if the earth's crust underneath had not yielded by sinking to admit more load. In Venice, borings of 173 meters did not reach the bottom of land-derived gravels; in Modena, the depth is 215 meters. (36)

The Aegean Sea also shrunk considerably. In the place of the Dardanelles there was a tortuous river flowing south, while the Bosporus was perhaps predominantly a small river flowing north. In between was the Marmara Sea, a much shrunken lake, landlocked and unconnected with the seas. A wide land bridge connected the Balkans with Asia Minor through which man and animals freely migrated. The Black Sea was much

THE MEDITERRANEAN REGION DURING THE LAST GLACIATION (Würm I.)

Fig. 13

smaller; the northern shallow shelf and the Azovian Sea were dry. There was then no Danube Delta as the old course of the river can be followed under the sea where it swings southward offshore from Constantsa. The level of the Black Sea was somewhat higher than that of the Mediterranean Sea - the Black Sea received the water of many large rivers, but not enough to overflow into the Mediterranean. (34) (36) It may have overflowed in the later stages to the Caspian Sea through the Manych Canal. (14)

In the Jefara near Tripoli, clay was deposited during the Monastirian stage carrying warm-water shells. This was partly eroded during the Würm I regression. At the same time dunes were formed at the shore. These dunes are now partly submerged reefs, paralleling the shore as shown in Fig. 12. (26)

The vegetation and climate of this stage can be traced by fossils, pollen analysis, and by extent of the loess cover. The Mediterranean region was traversed in summer by east-moving, fairly warm, and rain-bearing cyclonic storms. The southern areas which are now parched in the summer had abundant rain and North Africa was a rich grassland with forest at higher elevations. Mixed maritime forest occupied southern Spain, Italy, and the Balkans. Conifers and various kinds of tundra prevailed in higher and more northerly lands which were drier than at present. An unbroken steppe stretched from the present Hungary to Central Asia. (14)

One of the results of the lower levels of the seas and of the pluvial climate was that the powerful rivers cut deep channels into the

soft coastal-plain sediments. These channels later filled again, more or less, with sediments, but the channel of almost every larger river can be followed to the 50 fathom line on modern nautical charts if enough soundings are plotted. (2) The ancient Po and its tributaries are previously mentioned. North of the Black Sea, scores of invigorated rivers dissected the land rather deeply. This accounts for the present estuaries and valleys of the Dniester, Bug, Dnieper, Don, and many others. (36) The river channels which once debouched from the Atlas to the former east coast of Tunisia are well discernible - some even from air photos. Large rivers drained African areas of the later Sahara Desert, and a large lake formed over the present location of the Chotts. Whether these lakes ever drained across the Gulf of Gabes area to the former seashore is debated, but submarine channels abound in the Bay of Gabes.

The Rhone delta was studied by Richard J. Russell. The Crau gravels are found now inland in borings at -50 meters. He mentions a rather distinct bench at a depth slightly less than 100 meters beneath the waters south of the delta. (39)

Dramatic changes occurred at the Nile during these times. As mentioned before, the Monastirian Nile flowed east of Cairo, cut terraces (now at plus 15 meters), and built its delta toward the submerged area of the present Isthmus of Suez, where the fresh waters of the Nile prevented the mingling of the marine faunas from the north and south. During the Wurm I regression, the Nile flowed north to the coast over a rather steep slope. The increased rainfall and the new low base

level transformed the tranquil Nile into a rapid torrent of enormous power and several times its present volume. It cut deep into its former sediments and carved its present valley as far back as Aswan. Even this far south, the bottom of the gravel is below the present higher sea level. Near the landward head of the present delta, at Cairo, the bottom of the Nile sediments today lies at 82 meters below sea level; but at Zagazig in the eastern delta the bottom of a well at -105 meters is still in sands. In this latter case, local crustal subsidence may be the explanation; or, it seems possible that these sediments were laid down during the Roman (Mindel) or Riss regressions when the sea levels were still lower. (36)

The cutting down of the Nile also invigorated its erstwhile tributaries. The many present half-buried depressions may well have been the channels of the former members of the Nile system. This appears most likely in the cases of Wadi Natrun, Wadi Farigh, and the Fayum depressions, the sediments of which underlie their bottom by some 20 to 50 meters. (36) Whether the Qattara depression and the line of oases to Siva and Giarabub, the southern oases of Bahariya, and Farafra, or even Kharga and Dakhla - were formed by tributaries of the Greater Nile is probable but needs proof.

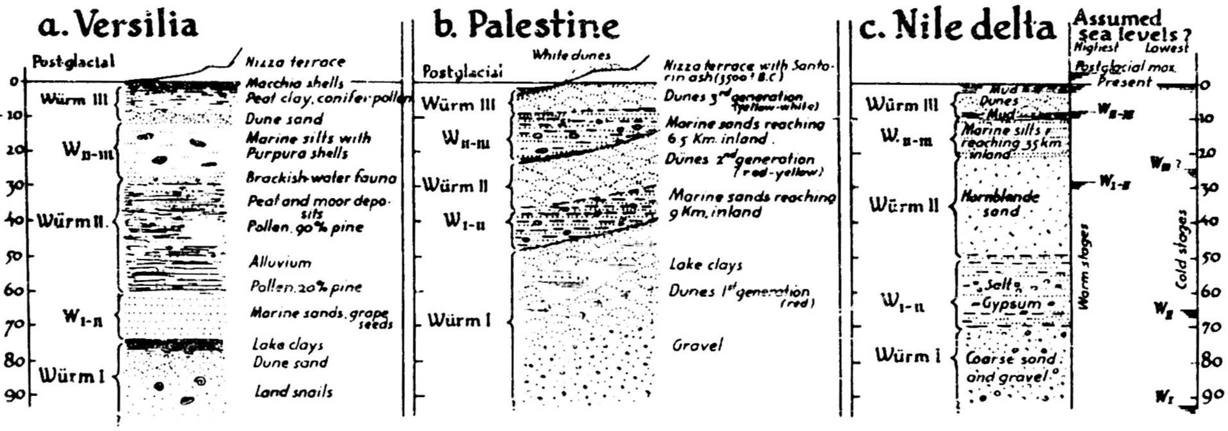
In America the Würm I is correlated with the Iowan which is also called Wisconsin I. In Northern Europe it produced the Flaming-Warthe moraine and the Little Eastern moraine in England.

9. THE FLANDRIAN TRANSGRESSION

Some scientists theorize that a decrease of 5°C in present average temperatures would induce a new ice age. However, the changes in temperature during the hundred thousand plus years of the Würm glaciation were greater than that. At least twice did the climate turn warm, whereby the ice caps diminished and the apparent sea level rose, to followed by re-advances of the ice correlating with lower sea levels.

In the Mediterranean, the marks left by the higher water levels of the warm stages generally remained well below the present surface of the sea. In the north countries, however, the earth's crust was relatively depressed by the weight of the ice and remained so for a while even after some of the ice melted. After this lag, the land was re-elevated. In Scotland, for example, we now find raised beaches of these times at about 30 meters above sea level and in Flandria at lesser heights. (47) The term "Flandrian Transgression" applies to all higher sea levels of the Wurm stage.

The sequence of these events in the Mediterranean margins was studied by A. C. Blanc by observations of borings in Versilia - the subapennine coastal plain north of Pisa - and by Pfannenstiel in Palestine and the Nile delta. (5) (46) (36) Their results are shown in Fig. 14.



a. Borings in Versilia near Pisa interpreted by Blanc and Tongiorgi

b. Borings in Palestine interpreted by Pfanren-stiel

c. Borings in the Nile delta interpreted by Pfannenstiel

FIG. 14 CHRONOLOGY OF THE LAST GLACIATION -- Borings show continental deposits from the cold and marine deposits from the warm periods.

WÜRM I-II -- The first warm substage, the time between Würm I and Würm II, is correlated with the Peorian loess in America. In the Mediterranean, the sea rose gradually about 30 meters and deposited sands, today found at 74 to 61 meters below the surface of the sea. Fossils in Versilia indicate warm waters, into which even seeds of grapes and the litter of an oak forest were washed. (5, 46) In Palestine the coarse gravels and sands (of the previous stage), washed down from the inland mountains, are covered with marine sands in a thickness of some 13 meters ranging between 45 and 32 meters below present sea level. In the Nile delta, salt and gypsum lenses are encountered between 69 to 50 meter depths, indicating this earlier warm-dry climate. About this time the Black Sea overflowed to the Mediterranean through the Bosporus - a route which has since remained open. (36)

WÜRM II -- The second re-advance of the ice was less intensive than that of Würm I. This second one produced the Pomeranian moraines in Northern Europe, the Little Welsh moraine in England (47), and is correlated with the Tazewell and Cary substages in America. In Versilia, peat-bearing clays are encountered at 60 meter depths. The gradual change in climate is indicated by analysis of the fossil pollens, mixed in the sedimentary layers. In relation to present sea level, at -60 meters 20% comes from pines, 70% from fir, and 10% from oaks, while at -45 meters 90% comes from a pine, which now grows only at elevations of 1800 meters in the Apennines, indicating a change to colder. In Palestine, gravel and above it sand dunes of the "second generation" belong to the Würm II. In the Nile Delta, coarse hornblende-sands were deposited by the invigorated river. (36)

WÜRM II-III -- This warm stage brought the sea level to about 10 meters below the present level. Marine Purpura (purple) shells of this age are found in Italy and around the margins of the Eastern Basin. The sea advanced four miles inland in Palestine and covered the Nile delta as far as Basandila, 35 kilometers south of Damietta. The ice withdrew to Scandinavia, and the Baltic Sea came into existence in the depressed belt around the ice. (36)

WÜRM III -- The Finiglacial of Northern Europe and the Mankato sub-stage of America produced a still smaller ice cap. How far down was the sea level of Würm III is not well established. Russell reports undecomposed vegetable material to a depth of 20 to 30 meters in the Rhone delta - these materials may possibly be of Würm III times. (39)

At Versilia and in Palestine dune-sand, such material was found at the depth of 10 meters. (36)

The regression of the sea produced dunes around the Mediterranean at the present shorelines. Some of these, and some of the earlier ones, were limo-bearing and hardened into limestone reefs. Particularly along the desert coasts, these reefs now parallel the shoreline for hundreds of miles; and, many a good ship has been wrecked upon them. These reefs produce good building material for local harbors. (26) Although we may well imagine that the dunes, which formed on the large cold coastal plains of the Würm I and II, were partly destroyed by waves of the sea of the warm periods, they may have been rebuilt during the succeeding transgressions. Many of the dunes produced at the times of Würm III contain pollens and other remains of cold-weather conifers. These "dunes of third generation" are light-colored and scarcely weathered. (36)

MAN DURING THE WÜRM GLACIATION -- Before the last glaciation, tribes of "Warm Mousterian" culture lived around the Mediterranean; their name is derived from a cave in the south of France. They were small sturdy people with protruding jaws of the Neanderthal race. In the warm period, they painted their bodies in lieu of clothing, and used bone and chipped flint for tools. Inventiveness was not their main virtue; their life resembled that of the earlier Paleolithic; but they managed to survive for a very long time. (30) (43)

When the climate became cold in the Würm I they adapted themselves. They utilized sea caves which were laid dry by the retreat

of the sea, but their camps on the shore are now submerged. They made better tools during the cold period, and must have worn single pelts, attached by rawhide, for protection against the cold.

Driven by advancing ice and vigorous winters of the Asiatic steppes, a new people of large stature and higher culture advanced upon the Mediterranean and replaced the Mousterians. They belonged to various races and a later tribe of them, the Cro-Magnons, became famous for their cave-wall paintings. Their first culture is called Aurignacian from a cave in Southern France. Their flint instruments were slender, blade-like, and often curved; javelins were of bone, reindeer horn, and ivory. Some of their tools were even polished. Fine Aurignacian remains are found from Poland to Northern Spain, none in Switzerland, and very few on the southern shores of the Mediterranean. Having such an advanced culture so far north places them in the warm period of Würm I-II (30), but they continued for a time into the ice advance of Würm II. The finest of these slender types of tools were found in the Loire-Saone region and named Solutrean culture. It is quite possible that this culture developed in the Würm II-III warm stage. A similar contemporaneous culture, Chatelperronian, is supposed to have come from Africa because skeletons of these people show negroid characteristics. (30)

During the last advance of the ice, Würm III, different culture prevailed along the Mediterranean coasts, the Magdalenian, remains of which are found from the Yenisei to Northern Spain. Magdalenian tools were not as fine as the best of the later Aurignacian (Solutrean)

work; but the people were of distinct artistic and inventive ability.

10. POST GLACIAL STAGE

Once more it became warmer and the ice retreated. So much ice melted that the sea stood some 4 to 5 meters higher, in relation to land, than at present; here its waves cut the Nizza (Nice) terraces. These terraces are rarely deeply notched in the coasts, but are well distributed. In about 3500 B.C. the Aegean volcano, the Santorin, erupted and ejected much ash which floated in the eastern Mediterranean Sea. Waves carried these ashes to various shores and deposited them at 4 to 5 meters above present shorelines. Pfannenstiel reports these ashes from the Arabian cemetery in Jaffa and from various Aegean islands. (36)

Why did this higher sea level retreat to the present level? The most likely answer seems to be that climate became colder and new ice formed. It is also possible that some crustal adjustments are responsible - there were several local changes in sea level since then. The columns of the Serapis temple in Puzzvoli are bored by sea mussels in their lower part - indicating a down-and-up motion of 6 meters since Roman times. Climatic fluctuations since the Ice Age are well established. Even at present we experience a warming period with the universal sea level rising, according to Marmer, about one-half inch per decade. (29) Recent subsidence of deltas is supported by Russell's report on the Rhone. (39)

THE STRAIT OF GIBRALTAR -- The main physical control for Mediterranean waters is the Strait of Gibraltar. The Mediterranean lies in a relatively dry and warm part of the globe and evaporates more water than it receives from rain and rivers. Thus it is more salty and denser than the oceans. Cold ocean-bottom water can not penetrate through the high sill of the Strait of Gibraltar; thus the temperatures of the depths of the Mediterranean Sea are remarkably warm - about 13°C (55°F). The Eastern Basin is slightly warmer than the Western. Some physical properties of the Mediterranean Sea are shown in Figs. 15 and 16.

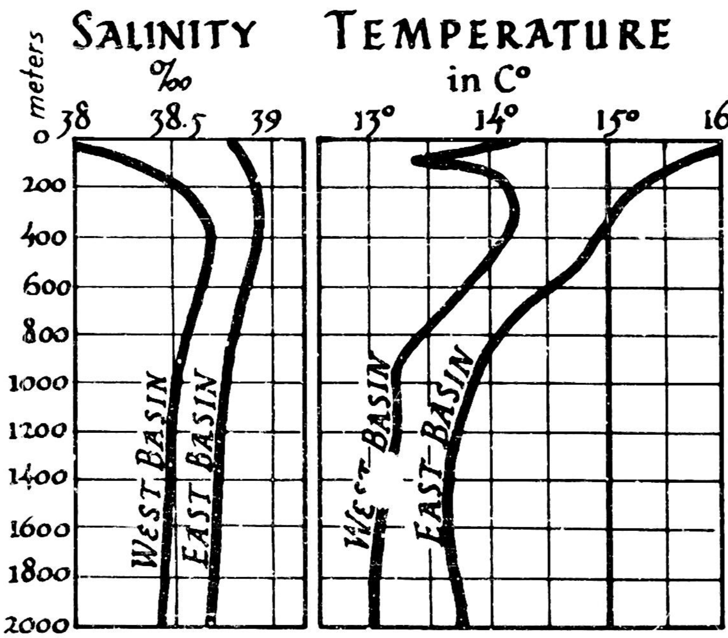
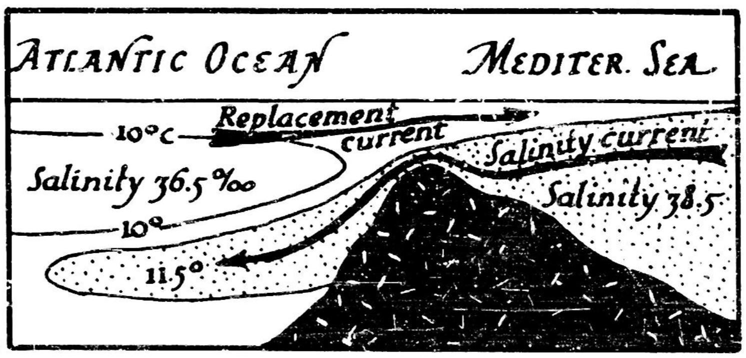


FIG. 15 SALINITY AND TEMPERATURE OF TWO STATIONS OF THE DANA SURVEY
Note relatively high temperature of the depths.

FIG. 16 THE STRAIT OF GIBRALTAR
The evaporation loss from the Mediterranean Sea is replaced by the surface current. The bottom current prevents Mediterranean waters from becoming more salty.



That the Mediterranean Sea does not get even more salty is due to the salinity counter-current at the bottom of the Strait of Gibraltar (20 km. wide, 320 m. deep). Heavy saline water slides westward down the sill; and this counter-current carries nearly as much water out to the Atlantic as the surface current brings in. It is fortunate that the average salinity of the Mediterranean Sea does not rise much over 38%, and thus it can maintain a rich fauna similar to other seas. Fig. 17 shows the nature of the currents across the sill of Gibraltar.

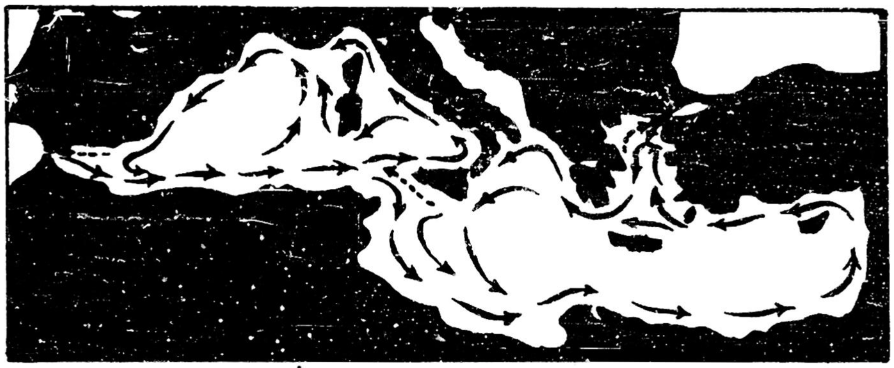


FIG. 17 CURRENTS OF THE MEDITERRANEAN SEA
These currents are weak and occasionally offset by winds. Bottom currents (dashed) carry highly saline water outward over the threshold of the straits.

The economy of the Mediterranean waters (after Kuenen) is the following:

	Km^3/year		Km^3/year
Inflow from Atlantic O.	54000	Outflow to Atlantic	52000
Inflow from Black Sea	400	Outflow to Black Sea	200
Rainfall	1000	Evaporation	3400
Rivers	200		55600 km^3
	55600 km^3		

If there were no Strait of Gibraltar, evaporation would exceed the water added by rain and rivers by 2200 km^3 per year and the whole sea would become, in a few thousand years, a desert studded with salt lakes and salt pans at various levels, some of which may be two miles below current sea level. Our civilisation could not have developed in this surrounding.

CULTURAL DEVELOPMENT -- The Mediterranean Region became the center of human progress. It would be beyond the purpose of this paper to trace the Neolithic development, the Bronze Age, and the Iron Age. However, the scene became set for the Egyptian, Minoan, Phoenician, Greek, and Roman civilisations. Here developed Judaism and Christianity, and here flourished the Moslem Culture. During the Renaissance the Mediterranean Region reached its cultural peak, but has declined somewhat since.

Our civilisation originated in the Mediterranean Region. Monuments of its great past abound everywhere. Every year thousands of Americans find inspiration there. Politically and strategically it is still important. Around the Mediterranean are located the center of the land area of the world (near Varna), the center of the world wealth (S. France). This region is called "the crossroad of mankind", and it is said that whoever controls it, controls the destiny of mankind.

SUMMARY

The Mediterranean Sea is the remnant of a much larger sea of the past - the Tethys which girdled the globe from Spain to Indonesia. Alpine orogeny folded and thrust the sediments of the Tethys Sea into high mountains, the Great Tertiary Ranges. These ranges broke up the Tethys Sea. The northern part, called Sarmatian Sea which extended from present Germany to beyond the Aral Sea, gradually emerged and is now mostly dry land. Basins between the folded ranges now form the Western Basin of the Mediterranean Sea and also the Adriatic and Aegean Seas. The Eastern Basin of the Mediterranean Sea is a "sub-alpine foreland", a lowland south of the Great Tertiary Range which once extended to the Indo-Gangetic plain and beyond, but was cut off by the northward extension of the Great Riff Valley of Africa. A great deal of up and down movement, foundering, and block faulting accompanied by much volcanism gave the Mediterranean Sea its present shape.

In the Quaternary period (Ice Age), tectonic changes still went on particularly in the early stages. The emergence of Italy and the Tell Atlas and the formation of the Aegean Sea were the main events. In the later stages the land changed little. It is not yet in still-stand, however, even today. During the Ice Age the main events were the ups and downs of sea level. Every glaciation withdrew millions of cubic miles of water from the seas and piled it up on land in the form of ice, lowering the sea level by hundreds of feet. Every warm inter-glacial period released these waters and flooded the coasts.

Four major glacial stages are recognized in Alpine Europe - the Günz, Mindel, Riss, and Würm - each followed by an interglacial stage although the Würm ice still covers Greenland and Antarctica. It seems that in every interglacial stage the land was flooded to a lesser and lesser height, thus producing a series of terraces at decreasing elevations above the present level of the Mediterranean Sea. These are the Calabrian at 180 meters and above, the Sicilian at about 100 meters, the Milazzian at approximately 60 meters, the Tyrrhenian at roughly 30 meters, the Monastirian at some 15 meters and the Nizza at 4 meters. The correlation of these terraces with the interglacial periods is still uncertain. Each glacial stage lowered the sea level much below the present level, but the evidence is now submerged and little known. Borings, however, indicate a -90 meter sea level at the maximum of Würm glaciation, after which followed two warm periods and re-advances of ice which can be correlated not only by marine deposits, but also with human cultures.

Never through its history, however, did the Mediterranean Sea stand long enough at a single level to complete or even advance very far in a marine cycle of erosion. The coasts are in a youthful stage of development which adds much to their beauty, but also to the navigational hazards, such as calcified dunes - now under the sea. The steep submarine slopes make anchorage difficult in many parts. More knowledge of the Mediterranean Sea will further enhance an appreciation of its beauties and dangers.

All the Ice Age correlations should be read with a grain of salt.

The whole sequence of four glaciations is challenged by many. That every interglacial stage produced a terrace just about one-half as high as the previous is just a little suspiciously neat. Until there are studies, based on more deep borings and on a great many more soundings, and until we know the bottom of the Mediterranean as well as the coast, much of this developmental history is based on assumptions. There is also another factor to consider. While glacial studies went on smoothly in America, they were rudely interrupted by war and impoverishment in Southern Europe. They are presently resumed, however, and the results of a decade may yield a much clearer understanding.

BIBLIOGRAPHY

1. Anteva, Ernst, "Maps of Pleistocene Glaciations, "Bull. Geol. Soc. Am., Vol. 40 (1929), p. 631. Washington, D. C.

2. Arnoulf, M., "Presence du quaternaire marin a Tunis," Bulletin de la Societe des Sciences naturelles de Tunisie, fascicule 1 (1948), pp. 30-31.

3. Blanc, A. C., "Sulla stratigrafia quaternaria dell'Agro Pontino e della Bassa Versilia, "Bollettino della Societa Geologica Italiana, Vol. 55 (1936). Roma.

4. Blanc, A. C., "Low levels of the Mediterranean Sea during the Pleistocene glaciation," Quart. Journ. Geol. Soc. of London, Vol. 93 (1937).

5. Blanc, A. C., "Variazioni climatiche ed oscillazioni della linea di riva nel Mediterraneo centrale durante l'Era glaciale," Geologie der Meere und Binnengewasser (serial edition), Vol. 5 (1942). Berlin. (Rich bibliography)

6. Boule, Marcellin, "Les Grottes de Grimaldi," Geologie et Paleontologie (Monaco, 1906).

Also see: "La Grotte de l'Observatoire a Monaco," Archives de l'Institut de Paleontologie humaine, Memoire 1 (Paris: Masson, 1927).

7. Daly, Reginald A., "Swinging Sea Level of the Ice Age," Bull. Geol. Soc. Am., Vol. 40 (1929), pp. 721-734. Washington, D.C.

8. De Marchi, G., "Variazioni del livello dell'Adriatico in corrispondenza con le espansioni glaciali," Atti [Proceedings] della Accademia Scientiae Veneto-Trentano-Istro (1923).

9. Denizot, Georges, "Apropos des terraces siciliennes et milazziennes," Comptes rendus de [Papers submitted to] la Societe Geologique de France (1947), pp. 55-60, 90-100, 136-137.

10. Desio, Ardito, "Ubersicht uber die Geologie Libyens," Geologische Rundschau, Vol. 33 (1942), No. 4-6, pp. 415-421. Berlin.

11. Desio, Ardito, "Le condizioni geologiche della Libia fra il pliocene ed il quaternario," Reports of the 18th International Geological Congress, London, 1948. Part 9 (1950), pp. 26-29.

12. Desio, Ardito, "Studii morfologiei solla Libia Orientale," Accademia Italiana. Viaggi di studio ed esplorazioni. E. Missione scientifica a Cufra (1931), Vol. 2 (1939), Part 3, 216p. Roma.

13. Doeglas, D. J., "Old beaches of the Mediterranean," Reports of the 18th International Geological Congress, London, 1948. Part 8 (1950), pp. 16-17 and maps.

14. Frenzel, K. and Troll, C., Map of vegetation at the climax of

last glaciation, printed in Arctic, Vol. 6 (1953), No. 1, p. 59. (Review by F. Kenneth Hare)

15. Furon, Raymond, "La Paleogeographie, Essai Sur L'Evolution Des Continents et Des Oceans." (Paris: Payot, 1941).

16. Gignoux, Maurice, "Les formations marines pliocenes et quaternaires de l'Italie du Sud et de la Sicilie." (Lyon, 1913).

17. Gignoux, Maurice, "Les couches a Strombes en Sardaigne, en Corse et dans la province de Rome," Annales de l'Universite de Grenoble, Vol. 28 (1916), No. 1.

18. Gortani, Michele, "Gli studi sui terrazzi fluviali e marini d'Italie dal 1925-34," Comptes rendus [Papers submitted] du Congres international de Geographie de Varsovie [Warsaw], 1934. Tome [Vol.] 2 (1936). Travaux de la Section II [Geographie physique].

19. Gortani, Michele, "Osservazioni su alcuni spianamenti e terrazzi della Sardegna meridionale," Rendiconti della Reale Accademia delle Scienze Italiana, Bologna. Class 6 fis, Vol. 39 (1935), pp. 77-82.

20. Gutenberg, Beno, "Changes in sea level, postglacial uplift and mobility of the earth's interior," Bull. Geol. Soc. Am., Vol. 52 (1941), p. 721. Washington, D. C.

21. Kober, Leopold, "Die Oregentheorie." (Berlin: Borntraeger, 1933).

22. Kober, Leopold, "Tektonische Geologie." (Berlin: Borntraeger, 1942).

23. Kossmat, Franz, "Palaeogeographie und Tektonik." (Berlin: Borntraeger, 1938).

24. Lafitte, Robert, "Plissements post-pliocenes et mouvements quaternaires dans l'Algerie occidental," Comptes rendus /Papers submitted7 Academie des Sciences, Paris, Vol. 215 (1942), No. 17, pp. 372-374.

25. L.I.G.U.S. /Laboratoire de l'Institut de Geographie de l'Universite de Strasbourg7, "Problemes Geomorphologiques Corses," Geomorphologie Dynamique (1952).

26. Lipparini, Tino, "Tettonica e geomorfologia della Tripolitania," Bollettino Societa Geologica Italiana, Vol. 59 (1940), No. 2, pp. 221-301.

27. Llopis Llado, Noel, "Los terrenos quaternarios del llano de Barcelona," Barcelona Instituto de Geologia y Topografia, Publication 6 (1942), 52p. with 12 figs.

28. Llopis Llado, Noel, "Los movimientos corticales intracuaternarios del NE de Espana," Estudios Geologicos (Revista publicada por el Inst. Invest. Geol. "Lucas Mallada"), No. 3 (1947), pp. 181-236.

29. Marmer, H. A., "Sea level changes along the coasts of the United States in recent years," Transactions of the American Geophysical Union, Vol. 30 (1949), p. 201. Washington, D. C.

30. Menghin, Oswald, "Weltgeschichte der Steinzeit." (Wien: Schroll, 1931).

31. Morosan, Nic. N., "Le Pleistocene et le Paleolithique de la Roumanie du Nord-Est," Analele Institului Geologiei al Romaniei, Bucuresti, Tome [Vol.] 19 (1939), pp. 1-160. (Bibliography of 282 titles)

32. Paterson, T. T., "On a world correlation of the Pleistocene," Transactions of the Royal Soc. Edinburgh, Vol. 60 (1942), Part 2, pp. 373-425.

33. Paeckelmann, Werner, "Neue Beitrage zur Kentniss der Geologie . . . Konstantinopel," Abhandlungen der Preussischen Geologischen Landesanstalt, Vol. 186 (1938), 202p.

34. Pfannenstiel, Max, "Die diluvialen Entwicklungsstadien und die Urgeschichte von Dardanellen, Marmarameer und Bosporus," Geologische Rundschau, Vol. 34 (1944), No. 7/8. (Rich bibliography)

35. Pfannenstiel, Max, "Klimatisch bedingte Spiegelschwankungen des Mittelmeeres im Quartar und die palaolithischen Kulturen," Mitteilungen der Geologischen Gesellschaft zu Wien, Vols.

36-38 (1943-45).

36. Pfannenstiel, Max, "Quartare Spiegelschwankungen des Mittelmeeres . . .," Naturforschende Gesellschaft zu Zurich, Vol. 96 (1951), No. 4, pp. 82-102.

37. Raisz, Erwin, "Landforms of the Near East," - Map 30"x22" (Cambridge, Mass., 1951).

38. Raisz, Erwin, "Landforms of North Africa," - Map 48"x22" (Cambridge, Mass., 1952).

39. Russell, Richard Joel, "Geomorphology of the Rhone Delta," Assoc. Am. Geog. Ann., Vol. 32 (1942), No. 2, pp. 147-254.

40. Sacco, Federico, "L'alta Italia durante l'era quarternaria," L'Universo (Firenze: Instituto Geografico Militare), February and March, 1939, pp. 77-86, 187-204. (paleogeog. map 1:1,000,000)

41. Sauer, Carl O., "Agricultural origins and dispersals." (New York: Am. Geog. Soc., 1952, Second Series, Bowman Memorial Lectures), 110p.

42. Sermet, J., "La cote mediterraneenne d'Andalousie entre Malaga et Almeria, etude morphologique," Comptes rendus [Papers submitted] du Congres international de Geographie de Varsovie [Warsaw], 1934. Tome 2 (1936), pp. 300-317.

43. Schwarzbach, Martin, "Das Klima der Vorzeit eine Einfuhrung in die Palaoklimatologie." (Stuttgart: Enke, 1950).

44. Seidlitz, Wilhelm, "Diskordanz und Orogenese am Mittelmeer." (Berlin: Borntraeger, 1931).

45. Toniolo, Ant. Renato, "Ricerche sulle variazioni dei litorali sabbiosi del Mediterraneo," Comptes rendus [Papers submitted] du Congres international de Geographie de Varsovie [Warsaw], 1934. Tome 2 (1936), pp. 318-328.

46. Tongiorgi, E., "Le variazioni climatiche testimoniate dallo studio paleobotanico della serie fiandriana nella pianura della Bassa Versilia presso il Lago di Massa Ciuccoli," Nuovo Giornale Botanico Italiano, Vol. 43 (1936). Firenze.

47. Wills, Leonard J., "Paleogeographical Atlas." (London: Blackie & Sons, 1951), 64p.

48. Woldstedt, P., "Das Eiszeitalter. / Grundlinien einer Geologie des Diluviums." (Stuttgart: Enke, 1929).

49. Wright, H. E., "Marine Terraces of the Coast of Lebanon," Bull. Geol. Soc. Am., Vol. 58 (1947), No. 12, pp. 12-42.

50. Zeuner, Frederick E., "The Pleistocene Period. Its climate, chronology and faunal succession," Ray Society, Vol. 130 (for 1942 and 1943), 322p. (London: Bernard Quaritch, 1945).